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# DOWELS EFFECTIVENESS INVESTIGATION BETWEEN ULTRA HIGH PERFORMANCE FIBER REINFORCED CONCRETE AND REINFORCED CONCRETE

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## ABSTRACT.

In the present study, the performance of Reinforced Concrete (RC) beams which were strengthened with Ultra High Performance Fiber Reinforced Concrete (UHPFRC) and dowels at the interface was investigated. RC beams with a length of 2.2 m strengthened with UHPFRC layers at the tensile side. Before the application of the layers, the interface between RC and UHPFRC was roughened. During the testing, the interface slips between UHPFRC and RC were recorded using Linear Variable Differential Transformers (LVDTs). The beams were tested under four-point flexural test. The results of the present study indicated that the dowels at the interface reduce the slips at the interface, delay the formation of cracks and result in higher load carrying capacity.

KEYWORDS: Dowels, interface characteristics, reinforced concrete beams, steel connectors, strengthening, UHPFRC.

## 1. INTRODUCTION

Safety of structures is of paramount importance especially in case of old substandard structures or structures damaged by earthquakes or other accidental actions. Existing strengthening and retrofitting methods present crucial disadvantages which are related to the high cost, the difficulty in the application and the low performance of the technique. The present study investigates the effectiveness of Ultra High Performance Fiber Reinforced Concrete (UHPFRC) as strengthening material using dowels at the interface between Reinforced Concrete (RC) members and UHPFRC layers.

There are several studies in the literature investigating the properties of the UHPFRC [1–4]. The last years research has been focused on the application of UHPFRC as repair and strengthening material. An analytical model for the prediction of the response of composite UHPFRC and RC elements was developed by Habel et al. [5]. UHPFRC was applied as repair material from Bruhwiler and Denarie [6], while Lampropoulos et al [7] developed a numerical model that predicts the performance of RC beams which were strengthened with UHPFRC. Paschalis et al. [8], conducted full scale tests to investigate the effectiveness of UHPFRC for the strengthening of RC beams. In this study, RC beams strengthened with UHPFRC layers, with and without the use of steel bars in the layers. The addition of steel bars in the layer resulted in high load carrying capacity of the strengthened beams. However, high values of slips at the interface between UHPFRC and concrete were recorded.

In the present study the performance of RC beams which were strengthened with UHPFRC layers and dowels at the interface has been investigated. This is a topic which has not been investigated in detail and needs further investigation.

## 2. EXPERIMENTAL PROGRAM

Six beams have been tested in the present study. Two RC beams prepared without any layer and used as control beams. In two beams, UHPFRC layers added at the tensile side and in two beam dowels added at the interface between UHPFRC and RC.

The reinforcement and the dimensions of the beams without any reinforcement are presented in Figure 1. In Figure 2, the dimensions of the layers and the position of the dowels are presented. The dowels were designed based on Greek Retrofitting Code [9].

## 3. PREPARATION OF THE SPECIMENS

Fine sand, GGBS, Silica Fume, Superplasticizer, High strength cement and steel microfibers were used in the mix design. In addition, a high percentage of fibers (3 Vol.%) was incorporated in the mix to achieve strain hardening. The interface was roughened using a needle scaler and the dowels placed in position using a drill. The preparation of the beams which were strengthened with dowels is presented in Figure 3.

## 4. PROPERTIES OF THE MATERIALS

Cubes with 10 cm sides, tested in compression according to BS EN 12390-3:2009 [10]. The compressive

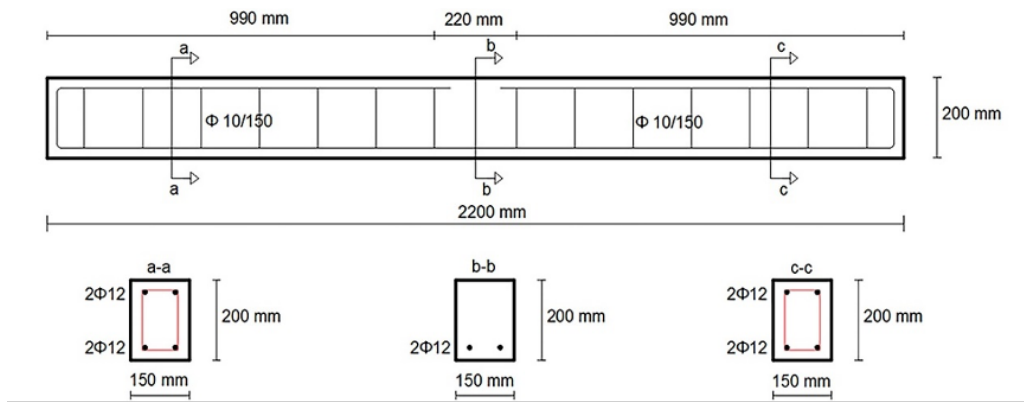


FIGURE 1. Control Beam.

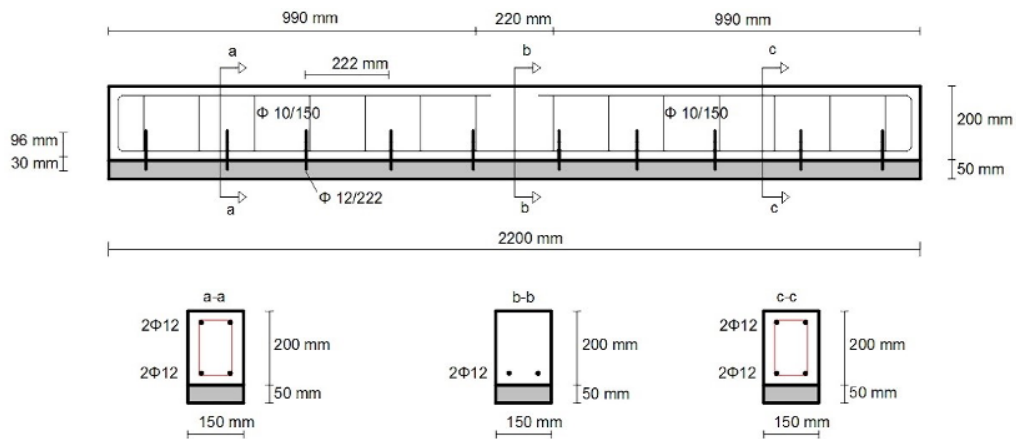


FIGURE 2. Strengthened beams using dowels.



FIGURE 3. Preparation of the beams.

strength of concrete which was used for the preparation of the beams was 31 MPa and the compressive strength of UHPFRC layers was 136 MPa. The tensile characteristics of UHPFRC identified with a direct tensile test. The results are presented in Figure 4.

Based on the average curve of Figure 4, the tensile strength was 11.5 MPa and the modulus of elasticity 50 GPa.

### 5. TESTING OF THE BEAMS

In Figure 5, a strengthened beam with layer before the testing is presented. As can be seen, LVDTs were placed at the interface between UHPFRC and RC to record the slip.

In Figure 7, the average experiments results are placed.

The Results of Figure 7 indicate the effectiveness of dowels. In both techniques, the stiffness of the beams was increased. However, with the addition of dowels a higher load carrying capacity was achieved. In this case, the maximum load was increased by 22.5%. On the contrary, an increase of only 1.5% was achieved with the addition of layers only.

In Figure 8, the beams after the testing are presented. The control beams failed with a major crack at the tensile side (Figure 8a). The failure mode of the two beams which were strengthened with UHPFRC

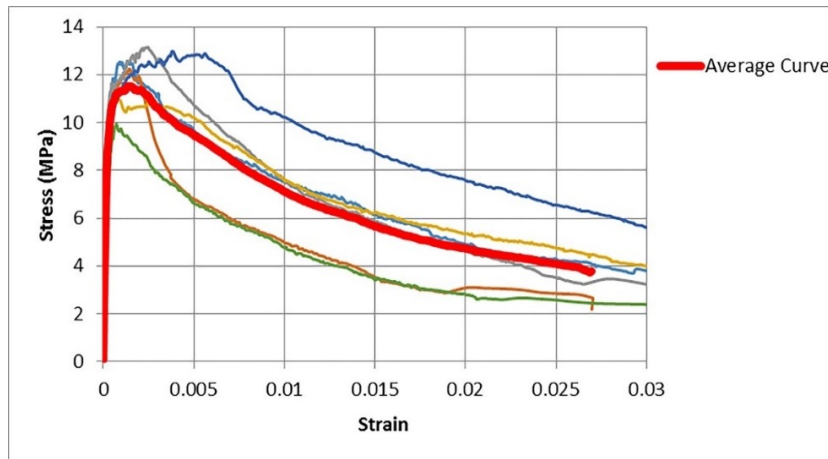


FIGURE 4. Stress-strain curve from the testing of UHPFRC in tension.



FIGURE 5. Experimental setup for the testing of the beams.

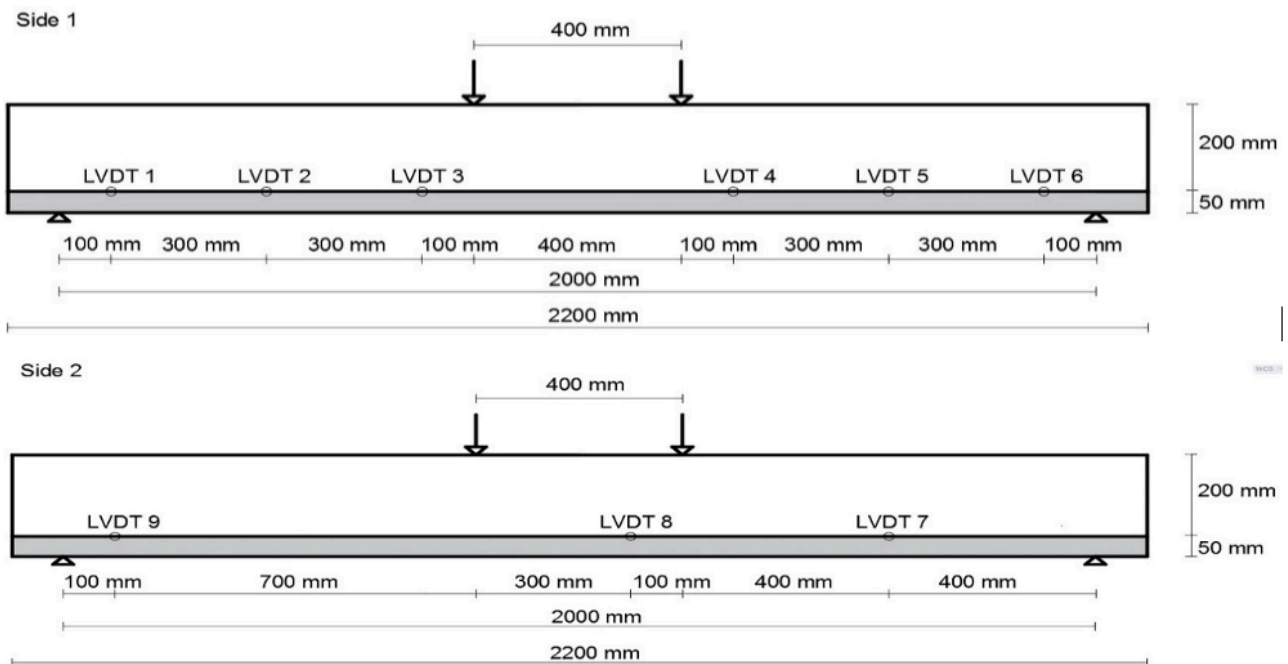


FIGURE 6. a) LVDTs on side 1 b) LVDTs on side 2.

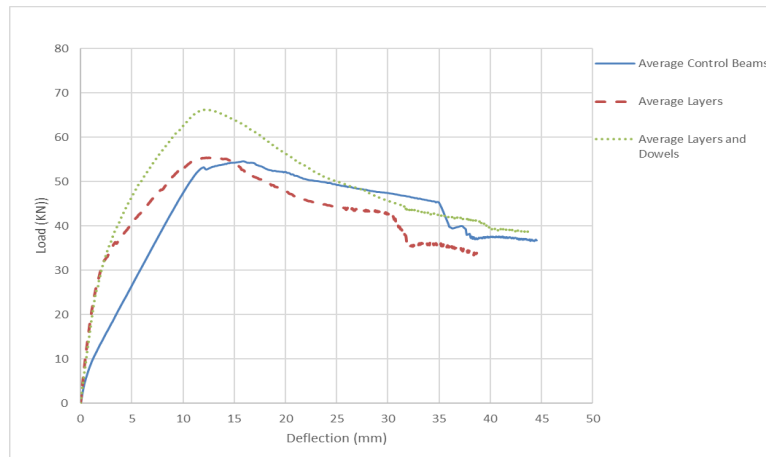


FIGURE 7. Results from the testing of beams.

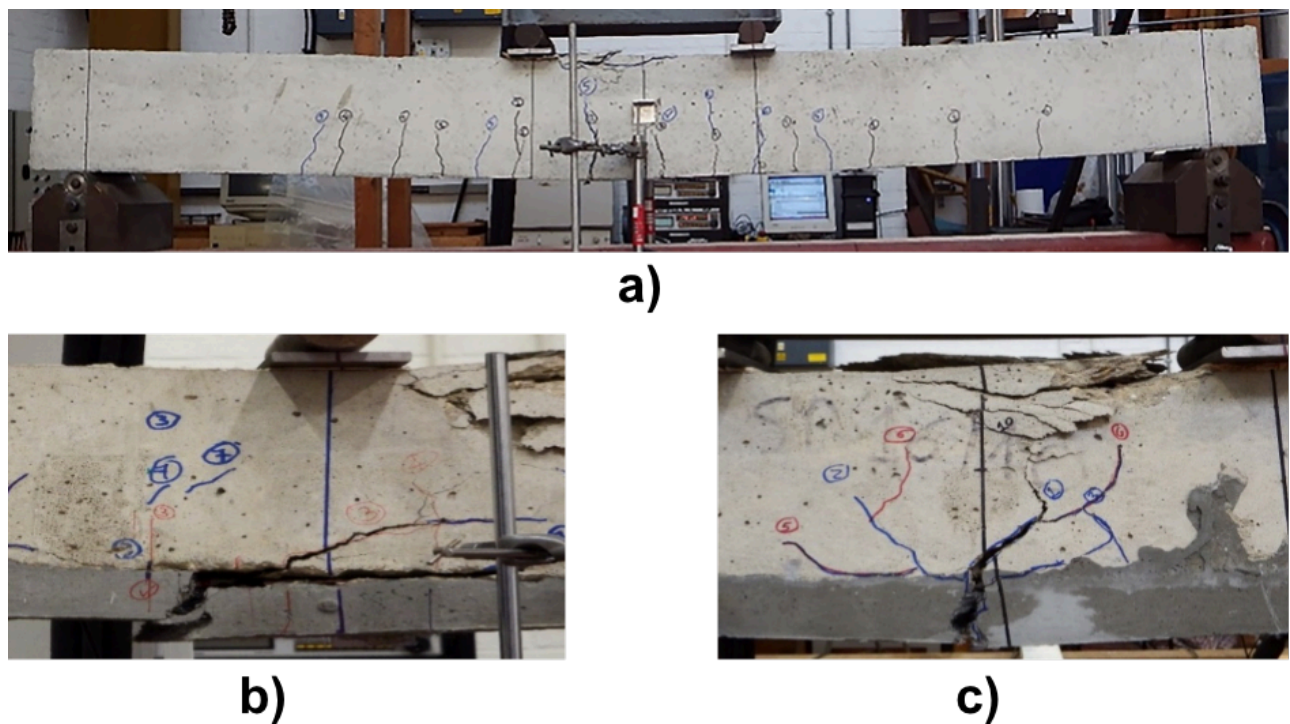


FIGURE 8. Failure mode a) Control Beam b) Beam strengthened with layer c) beam strengthened with layer and dowels.

layers was not the same. In one beam the bond at the interface was strong and a major crack at the layer progressively propagated to the RC beam. In the second beam, a de-bonding at the interface occurred (Figure 8b). Finally, identical was the failure mode of beams which were strengthened with layers and dowels. A major crack appeared in the layers and propagated to the RC beam (Figure 8c).

During the testing it was noticed that dowels resulted in the delay of the formation of cracks. This was also evident from the results of Figure 7. The cracking on the control beams started at value of load 5 kN, on the strengthened beams with layers at 15 kN and on beams with layers and dowels at 24 kN.

The results from the measurements of slips at the interface are presented in Table 1. Due to the fact

that a local debonding commenced in one of the beam which was strengthened with UHPFRC layer, the reading of this beam were ignored.

LVDT	Layers 1	Dowels 1	Dowels 2
2	0.06	0.04	0.01
3	0.11	0.01	0.18
4	0.36	0.05	0.06
7	0.03	0.03	0
8	0.18	0.14	0.01

TABLE 1. Reading of the LVDTs.

From the results of Table 1, it can be noticed that almost in all positions, the values of slip for the beams with dowels at the interface, were significantly lower

compared to the slips of the beam without dowels. This indicates the better bonding at the interface when dowels are used.

## 6. CONCLUSIONS

The main aim of the present study was to investigate the effectiveness of dowels at the interface between UHPFRC and RC. Full scale tests were conducted and RC beam with a length of 2.2 m strengthened with UHPFRC layers, with and without dowels. The slips at the interface were also recorded. Based on the experimental results the following conclusions can be drawn:

- Dowels delay the formation of the cracking
- Dowels result in a better bonding
- Dowels result in a higher load carrying capacity

Based on the findings of the present research, the use of dowels should be considered in cases that better bonding and better performance of the strengthened elements is required.

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